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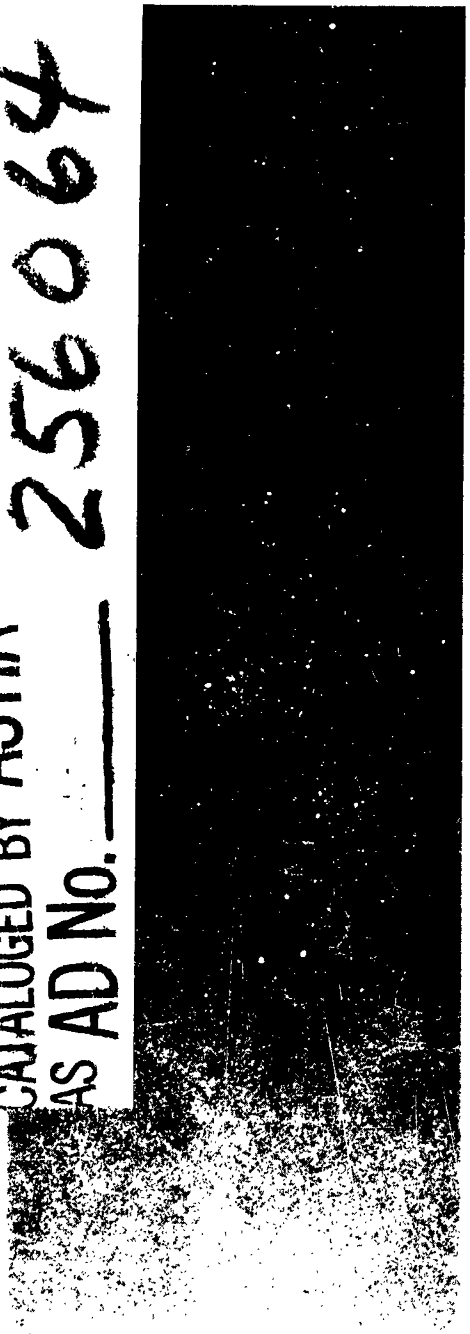


QUARTERLY TECHNICAL PROGRESS REPORT No. 4

DEVELOPMENT OF ION PROPELLANT SYSTEM

(TRW PROJECT No. 512-007946-08)

Report Period 15 December 1960 to 15 March 1961
Contract No. AF 33 (616)-7219, Item II
Project 3084 – Task 30273

PRESENTED BY:

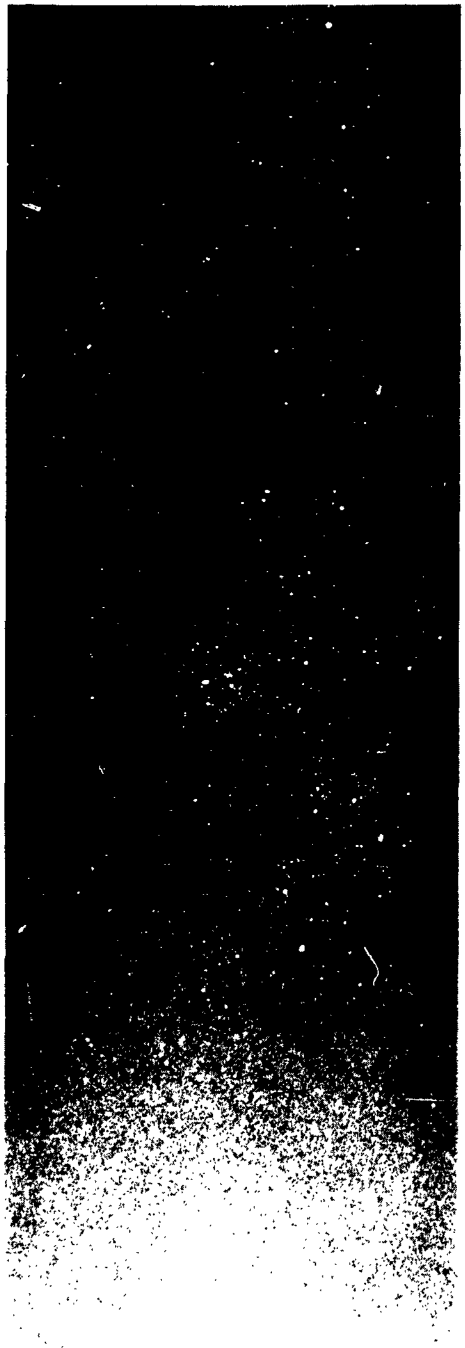
TAPCO GROUP

March 24, 1961

Thompson Ramo Wooldridge Inc.

$2.60

ER-4388



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1.0 INTRODUCTION

The fourth Quarterly Progress Report is submitted in compliance with Item II of Contract AF 33(616)-7219. This report covers development effort on the ion propellant prototype during the period beginning December 15, 1960 through March 15, 1961.

The object of this contract is to construct, test and deliver a complete prototype propellant system. The system is to have capabilities of storing 25 pounds of cesium and delivering cesium vapor at a flow of 5×10^{-5} pounds per second at 14 mm Hg pressure.

This prototype system is presently being assembled. Each component of the final system has undergone a complete development effort during the past twelve months, culminating in separate environmental tests before being integrated into the prototype. Some original plans (i.e., non-wetting porous vaporizer, etc.) had to be set aside in light of subsequent feasibility experiments with the alkali metal, however, in the past year's activity considerable valuable alkali-metal engineering experience has been gained, hitherto unavailable in the field.

The major portion of work on the ion propellant system during this reporting quarter has been devoted to completing tests on a final pump and vaporizer combination and to fabrication and assembly of a prototype system for endurance testing.

As a result of the pump and vaporizer tests a compatibility problem area was uncovered, (see Section 2.4) which has caused a slight delay in the expected completion date of the prototype assembly.

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All components incorporated in the prototype have been tested in expected operating conditions and have proved reliable.

Section 2.0 discusses the tests and activities undertaken during this reporting period. Section 3.0 reviews anticipated activities.

2.0 WORK ACCOMPLISHED DURING REPORTING PERIOD

2.1 Test Operations

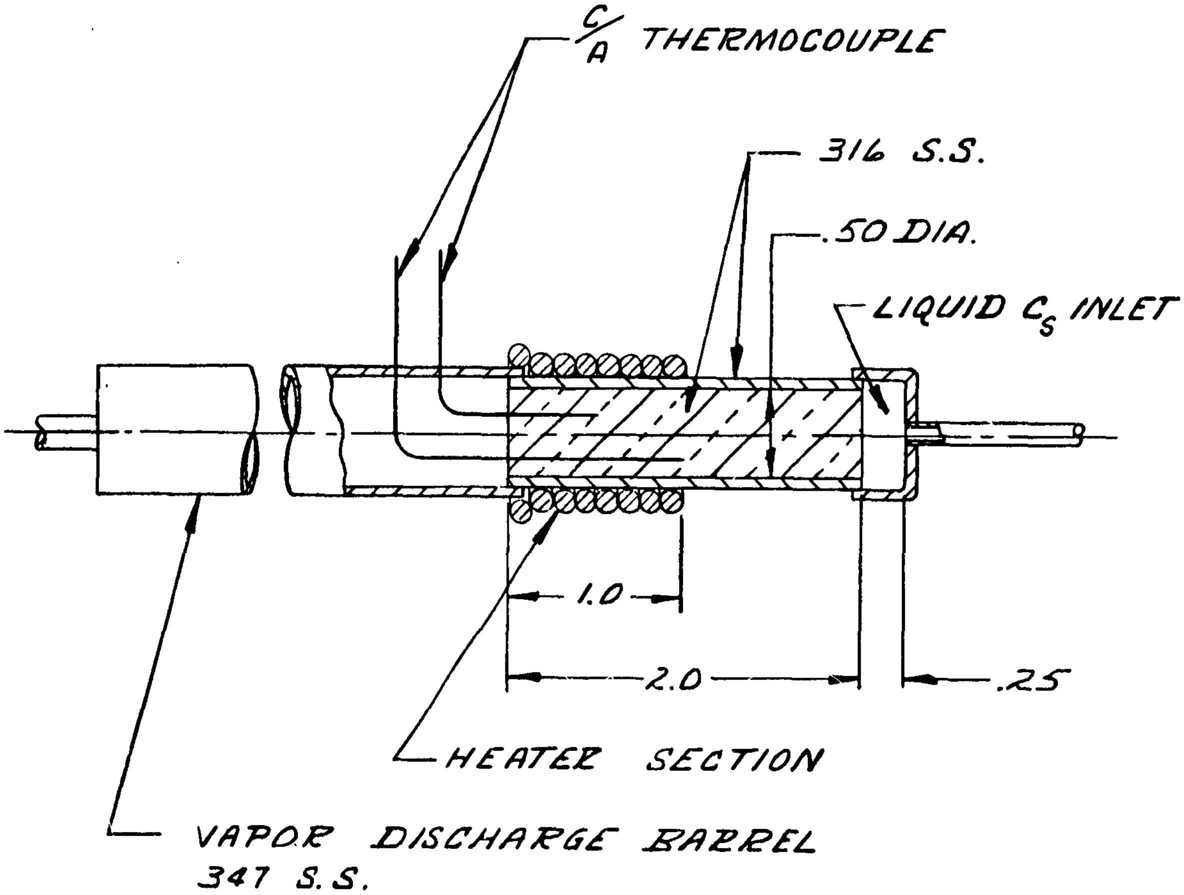
In February a two-week test period of the porous cesium vaporizer and metering pump was completed. During this period the unit was actually operating for approximately 30 hours. During periods of inactivity the vaporizer section was held at 200°F. System components, heaters, etc., all operated satisfactorily. Sheathed thermocouples in contact with cesium vapor during the entire test period exhibited no indications of corrosion.

During this test, chromel alumel thermocouples were embedded in the matrix mass (see Figure 2.1-1). These were included to collect information on the vaporizer temperature gradients during all phases of operation. A secondary reason for the use of these thermocouples was to determine the actual location of the vaporizing interface.

The thermocouples were able to render pertinent data on the temperature gradient of the matrix. However, they failed to precisely locate the vaporizing interface although the temperature maintained at the monitored depths indicate that under specified flow rates the interface is within 1/4 inch of the liquid inlet face.

Figure 2.1-2 presents an estimated temperature gradient, based on data collected during vaporizer operations by inserted and surface thermocouples. Although not specifically delineating the interface, this information has served to illustrate the variations in conductivity in the body of the matrix.

TYPE 316 VAPORIZER TEST ASSEMBLY



MATRIX SPEC.
AVG. PORE SIZE - 10 MICRON
POROSITY - 35 %

FIGURE 2.1-1

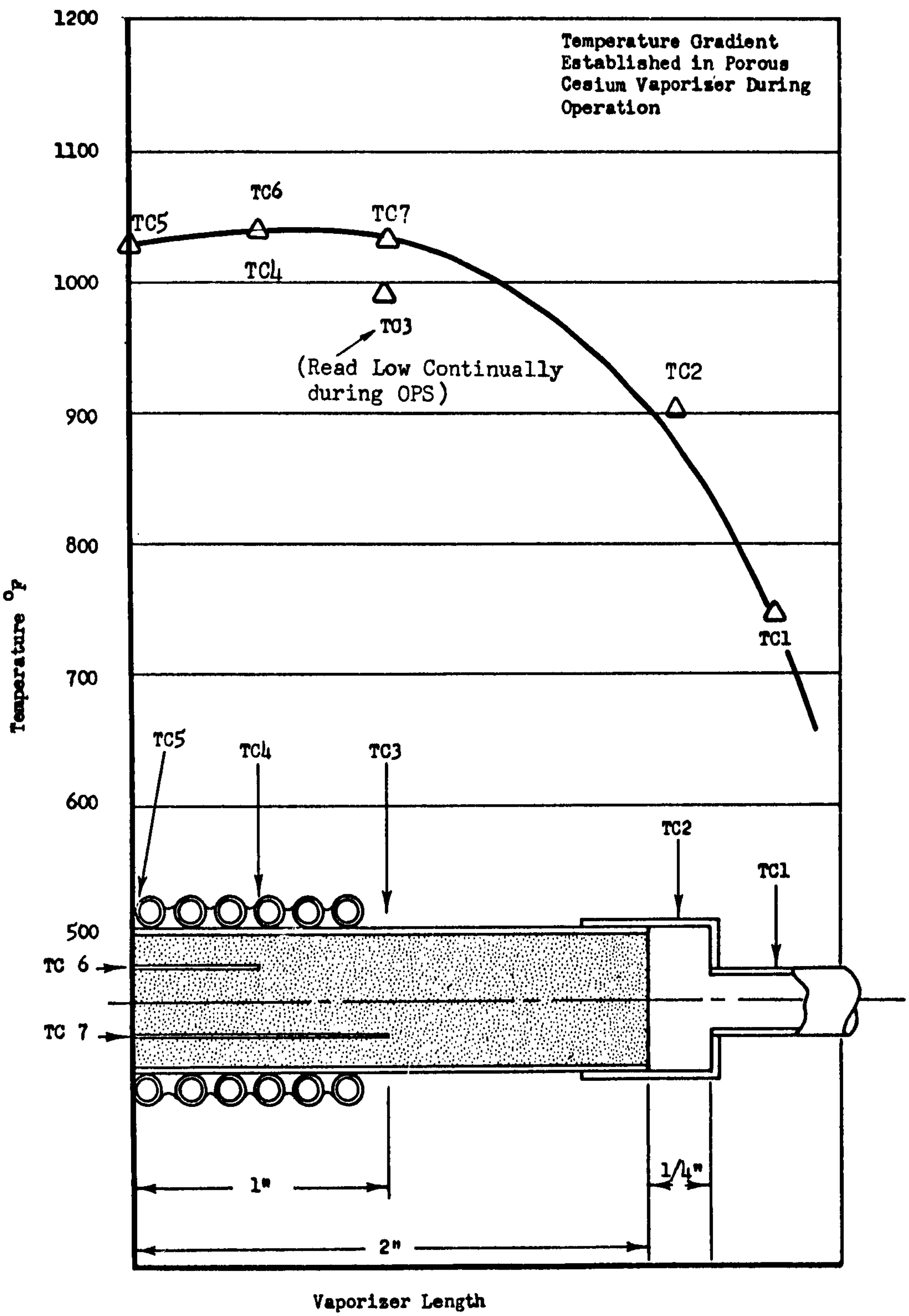

Temperature Gradient Established in Porous Cesium Vaporizer During Operation
1200
1100
1000
900
800
700
600
500
Temperature °F
TC5
TC6
TC7
TC4
TC3
(Read Low Continually during OPS)
TC2
TC1
TC5
TC4
TC3
TC2
TC1
TC 6
TC 7
1"
1/4"
2"
Vaporizer Length

Figure 2.1-2

Recent experience in preparing cesium vaporizers for service has led us to eliminate cleaning chemicals from the matrix structure in belief that even small amounts of alcohols or pure acetone cannot be adequately removed from the matrix prior to use. Instead we are presently preparing these components by a thorough outgassing at 10^{-5} mm Hg and 700°F. Essentially this is all the preparation performed on the matrix used in the two week test effort.

To acquire more operating information on the prototype metering pump, one pumping unit was assembled and operated in the vaporizer system during the latest test effort. A number of voltage settings were applied to the pump and resulting flows measured visually. Over a range of inlet pressures and motor voltages, the flow rates agree closely to the pumping data obtained during past cesium work.

The motor used in our tests to date is rated at 1.1 rpm (6 volts). Although this motor is capable of delivering the required flow rate (2.54 cu in/hr 5×10^{-5} #/sec) it requires the application of approximately 8 - 9 volts to maintain this rate. In order to develop a pumping unit which will deliver the required rate without the necessity of overpowering, the prototype system pump will be equipped with a slightly higher speed motor. Data will be collected from prototype operations to substantiate expected pump performance.

2.2 Vaporizer Development

The cesium vaporizer for the final prototype is presently being instrumented and should be installed in the very near future. For reasons outlined in Section 2.4 the entire vaporizer is of type 347 Stainless Steel construction.

Figure 2.2-1 shows a schematic of the prototype vaporizer assembly. A sheathed thermocouple has been installed in the vapor discharge area to monitor the cesium conditions as supplied by the matrix. A repositioning of weld locations and change of materials should provide a maximum of fabrication integrity.

Figure 2.2-2 is a photograph of the matrix vaporizer in position with the prototype metering pump. This separate system will be cleaned, leak detected, and welded into the prototype system.

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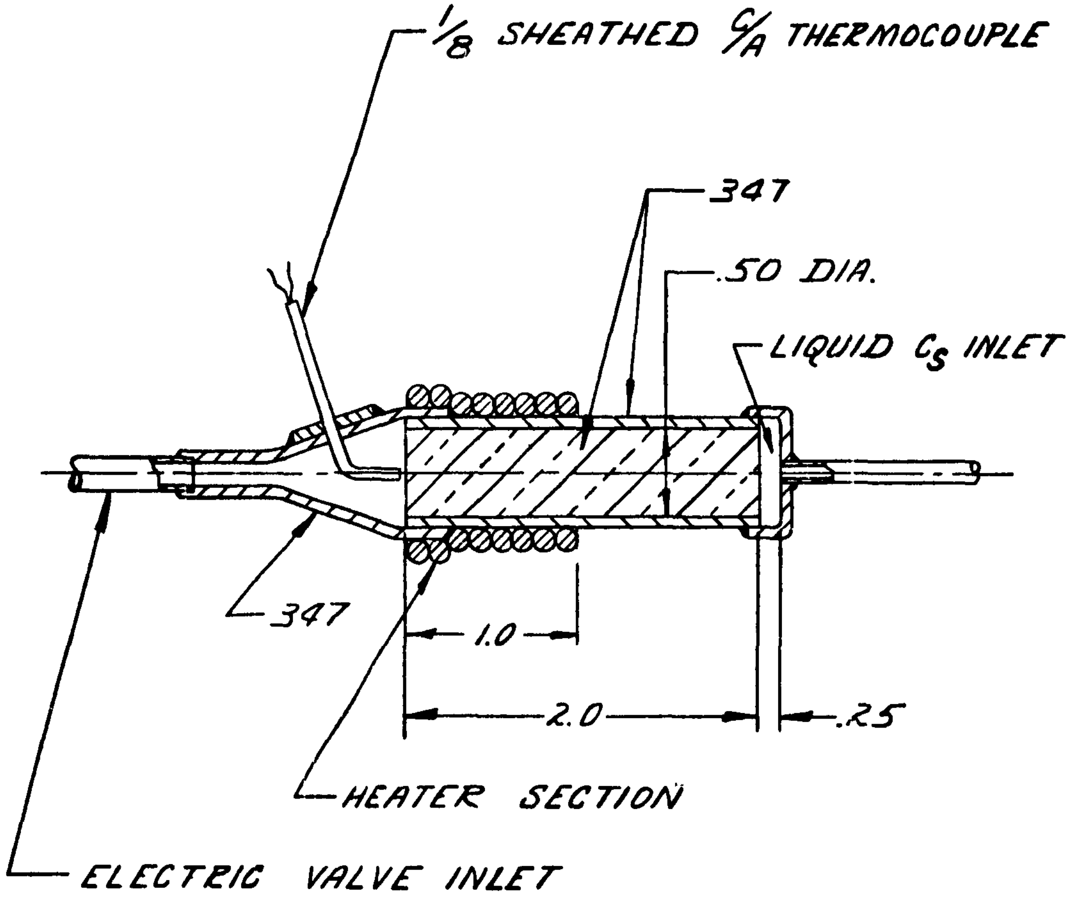
PROTOTYPE VAPORIZER ASSEMBLY



MATRIX SPEC.
AVG. PORE SIZE - 10 MICRON
POROSITY - 35 %

FIGURE 2.2-1

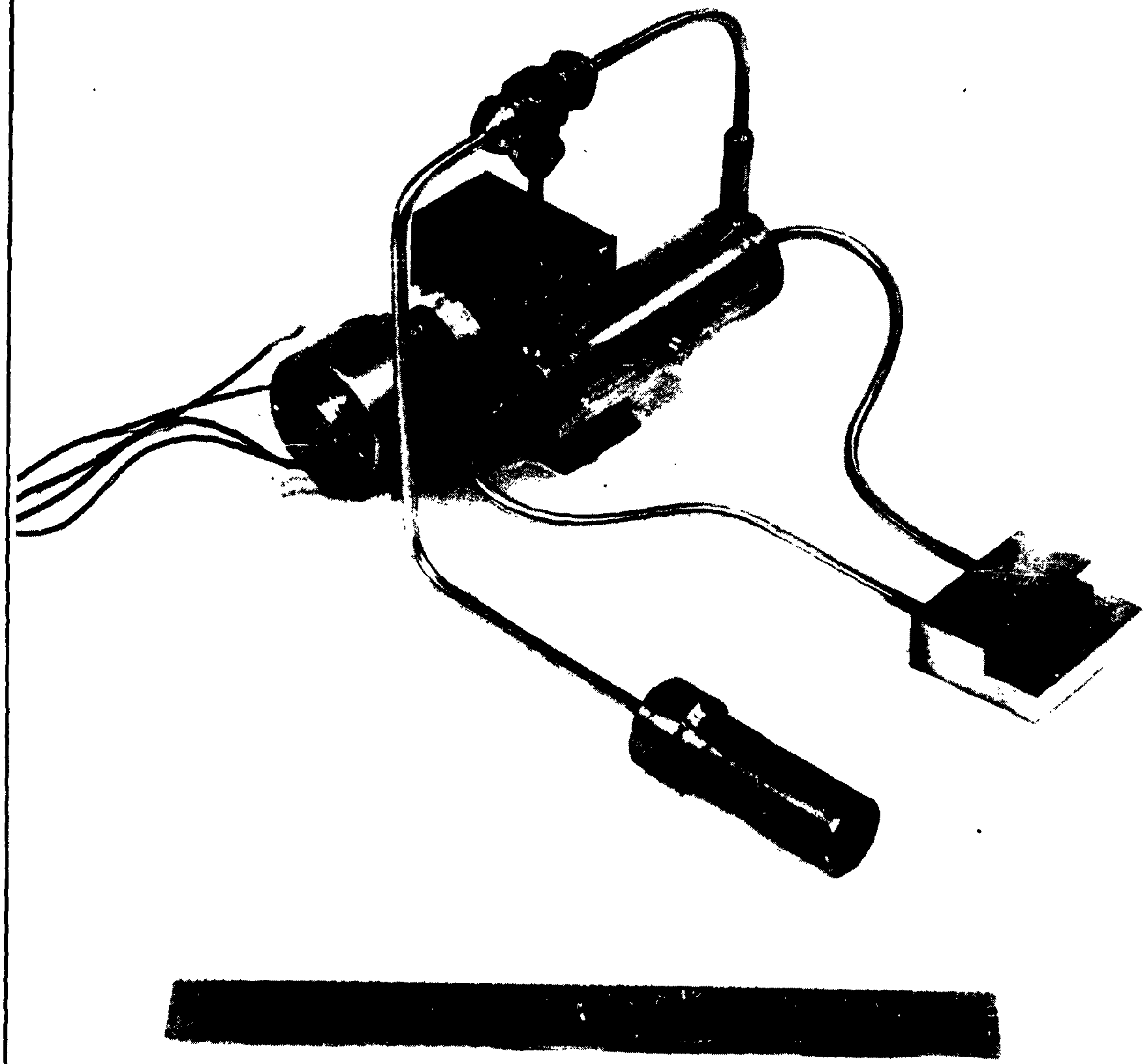


Figure 2.2-2

Prototype Pump and Vaporizer

2.3 Pump, Valve and Control Development

As outlined in the third Quarterly Technical Progress Report (ER-4294), TRW is completing development of electrically operated cesium system valves for the propellant supply system prototype. One valve will be used in 1000°F vapor service and one in 200°F liquid service. Initial feasibility tests on these units were completed during the past quarter period. These tests were primarily made to determine:

(a) Overall applicability of the valve design.

(b) Compatibility of the prototypes for their respective environments.

(c) Ability of the valve design used to provide completely hermetic sealing on shut-off.

To arrive at an evaluation of these factors, a test stand was assembled and the expected operating condition duplicated. A sample valve was used through approximately 3800 cycles before tests were stopped. The minor modifications noted above include strengthening of actuator arm, etc. to insure precise operation of the final valves during complete system tests.

With the inclusion of design modifications the fabrication of the prototype valves was begun. At each step in this fabrication process those valve surfaces to be in contact with cesium were cleaned and kept free of possible contamination. These prototype valves have all been tested for required sealing and two units (one liquid, one vapor) are installed in the prototype assembly. Figure 2.3-1 shows one of the completed valves.

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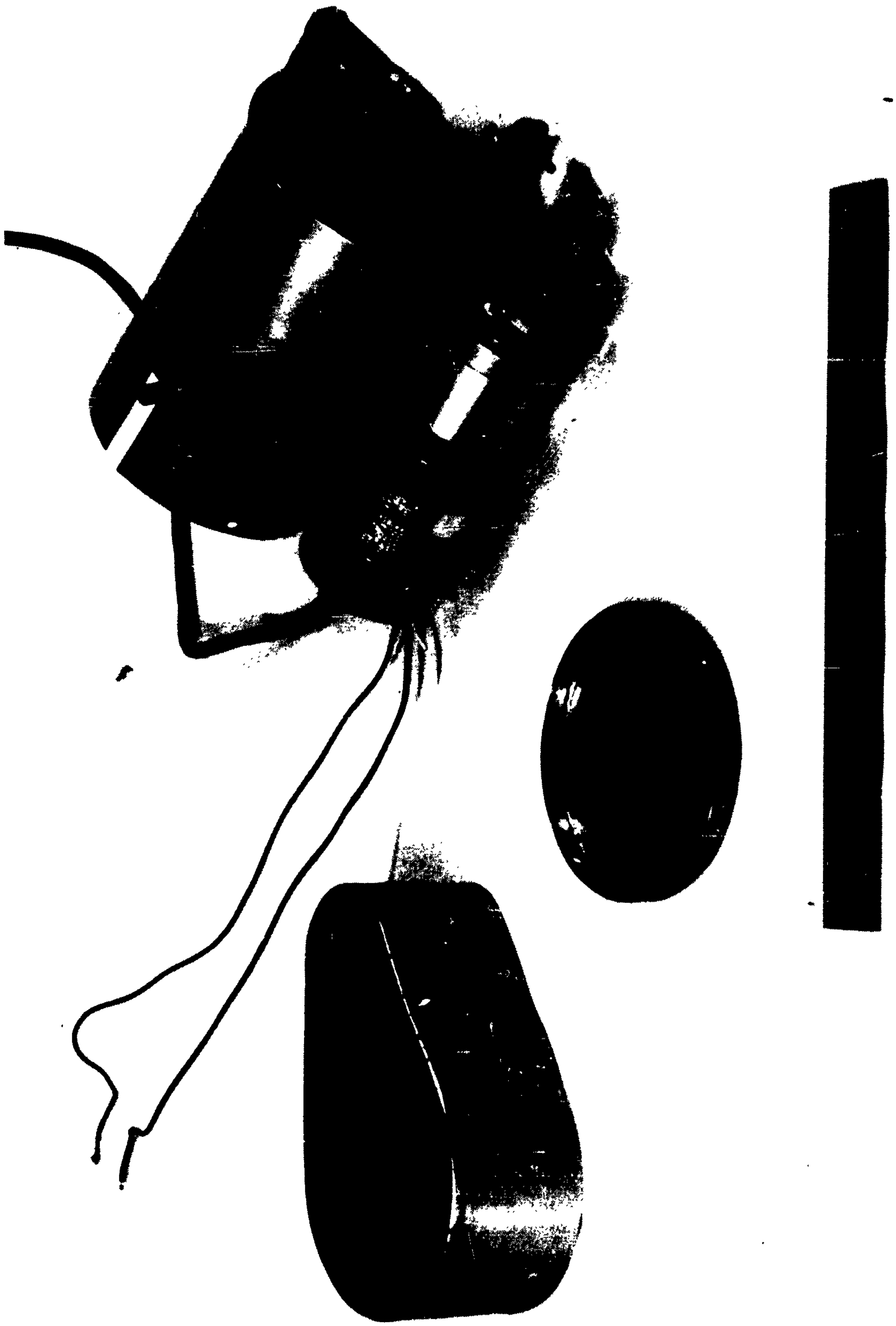


Figure 2.3-1

Electric Cesium Valves

On conclusion of the latest cesium flow tests which substantiated the reliability of the bellows pump design (Figure 2.3-2), assembly of a prototype pumping unit was begun. Fabrication of this component has been completed; the unit has been cleaned and hermetically checked.

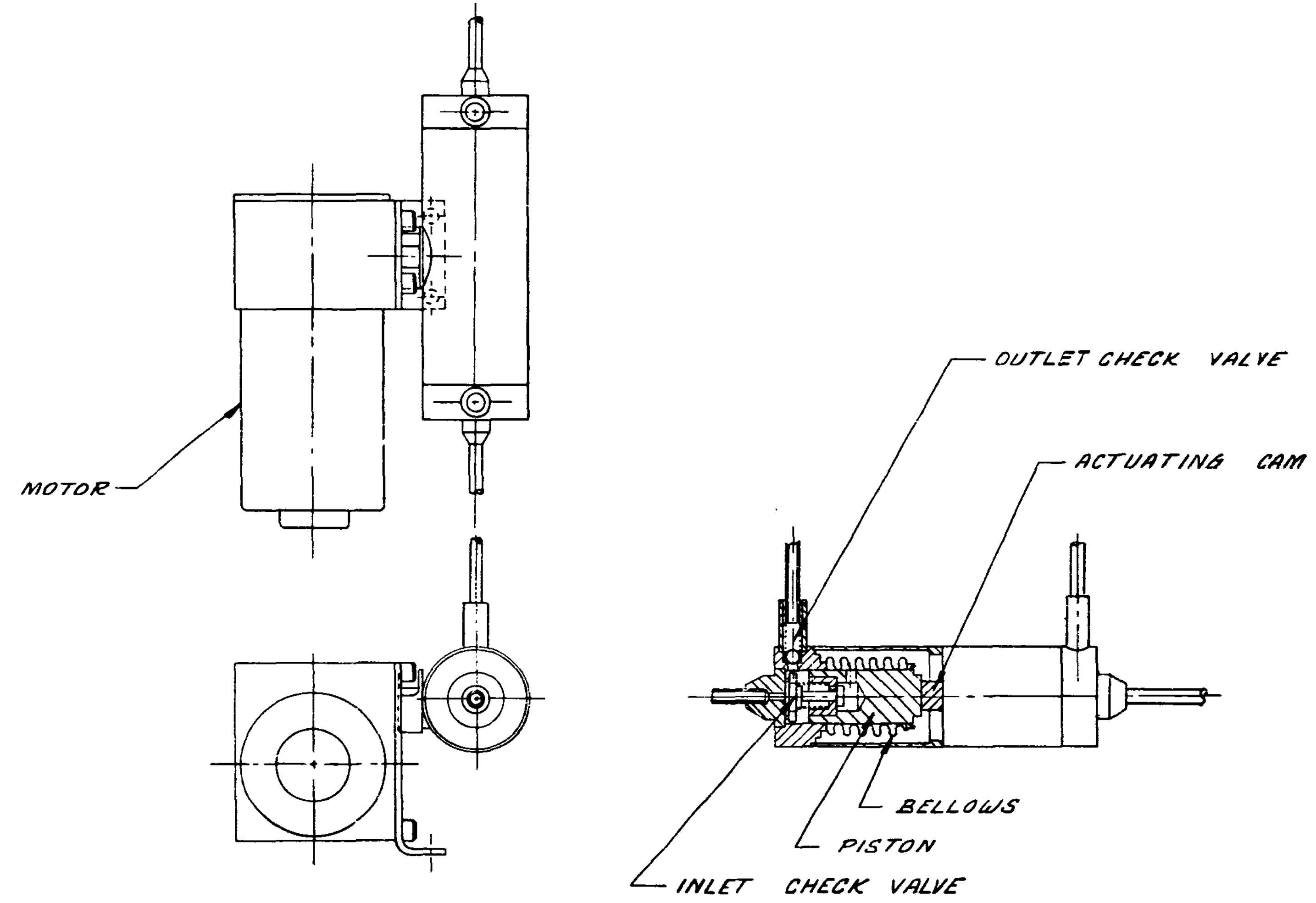
The assembly of a complete cesium prototype system, including pumps, valves, etc., which will experience operations in both low temperature liquid and high temperature vapor service requires critical surveillance of welding, brazing, and cleaning operations.

Welding of lines, valves, etc., requires heliarc operation with careful argon backing. Without such gas cover, oxides forming in areas of alkali metal activity could cause disastrous effects during high temperature operation. Since most pieces to be welded have been chemically prepared beforehand, welding tasks are generally painstaking and tedious.

As has been our practice in the past, all equipment exposed to cesium has been chemically cleaned before assembly by means of electropolish, acetone, etc. The fully assembled unit will also have to be leak detected and thoroughly outgassed before cesium testing.

Brazing operations have been accomplished using BT, vacuum type braze. We have found in the past on the ion propellant development and cesium diode projects that this braze is acceptable for cesium environments up to 1200°F.

Figure 2.3-3 is a photograph of the propellant system taken during final stages of assembly. This photograph shows finished components and prototype support. At the time this photograph was taken, line heaters,



CESIUM LIQUID MOTOR & PUMP ASSEMBLY

FIGURE 2.3-2

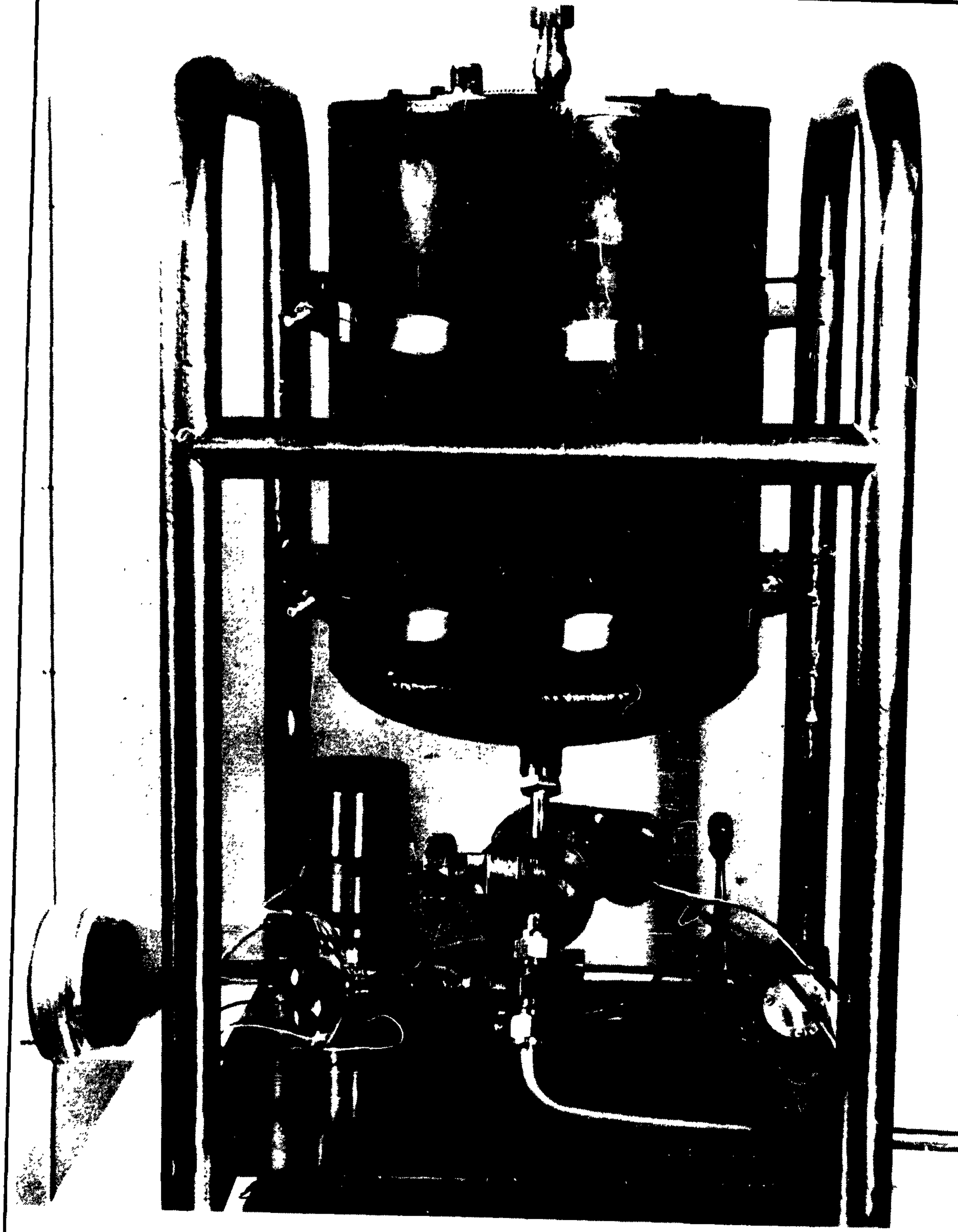


Figure 2.3-3

Prototype Propellant System in Final Stages of Assembly insulation, control wiring, etc. had not been installed. Figure 2.3-4 was included in this report to illustrate schematically the operation of the cesium system during subsequent tests.

The prototype control console has been completed during the past reporting quarter. The unit, shown in Figures 2.3-5 and 2.3-6 will function to monitor, record and control the operation of system vaporizer, storage tank, pump and valves. During all system tests the prototype will operate entirely within its environmental box and be regulated remotely via the control console.

Separate component response tests have been underway since console completion. Integration of the complete control system should be completed in the immediate future.

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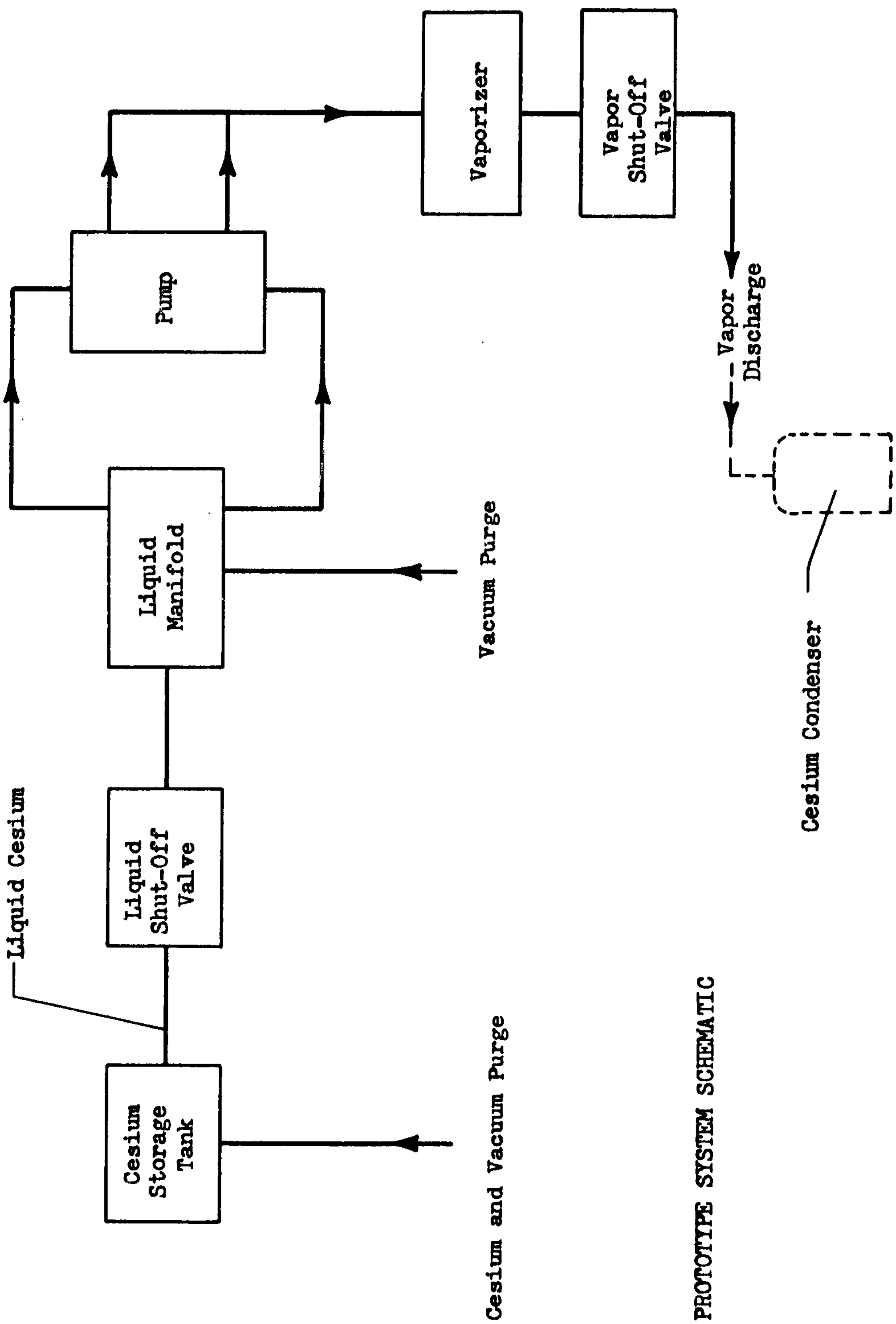

PROTOTYPE SYSTEM SCHEMATIC

Figure 2.3-4

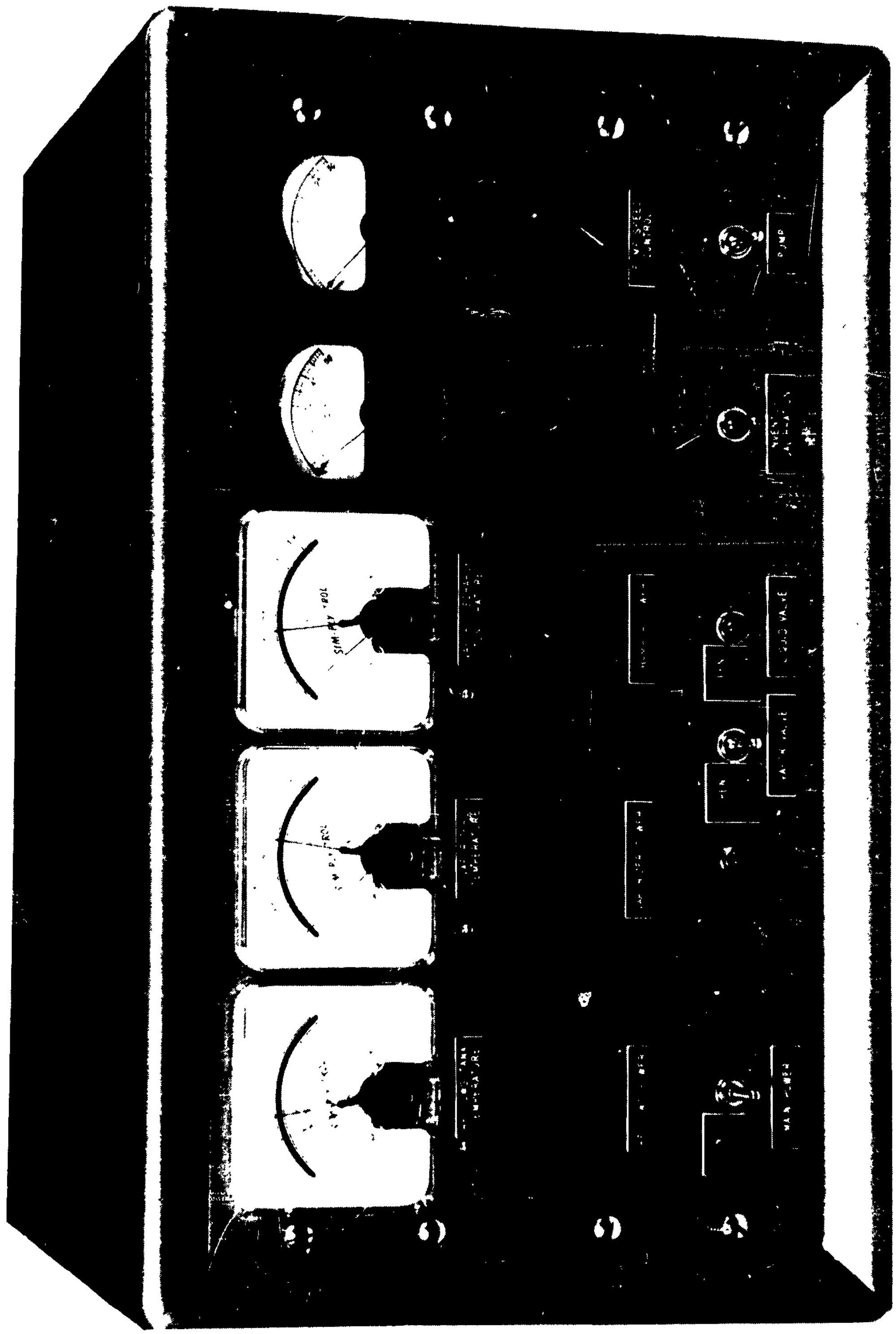

Figure 2.3-5
Prototype Control Console

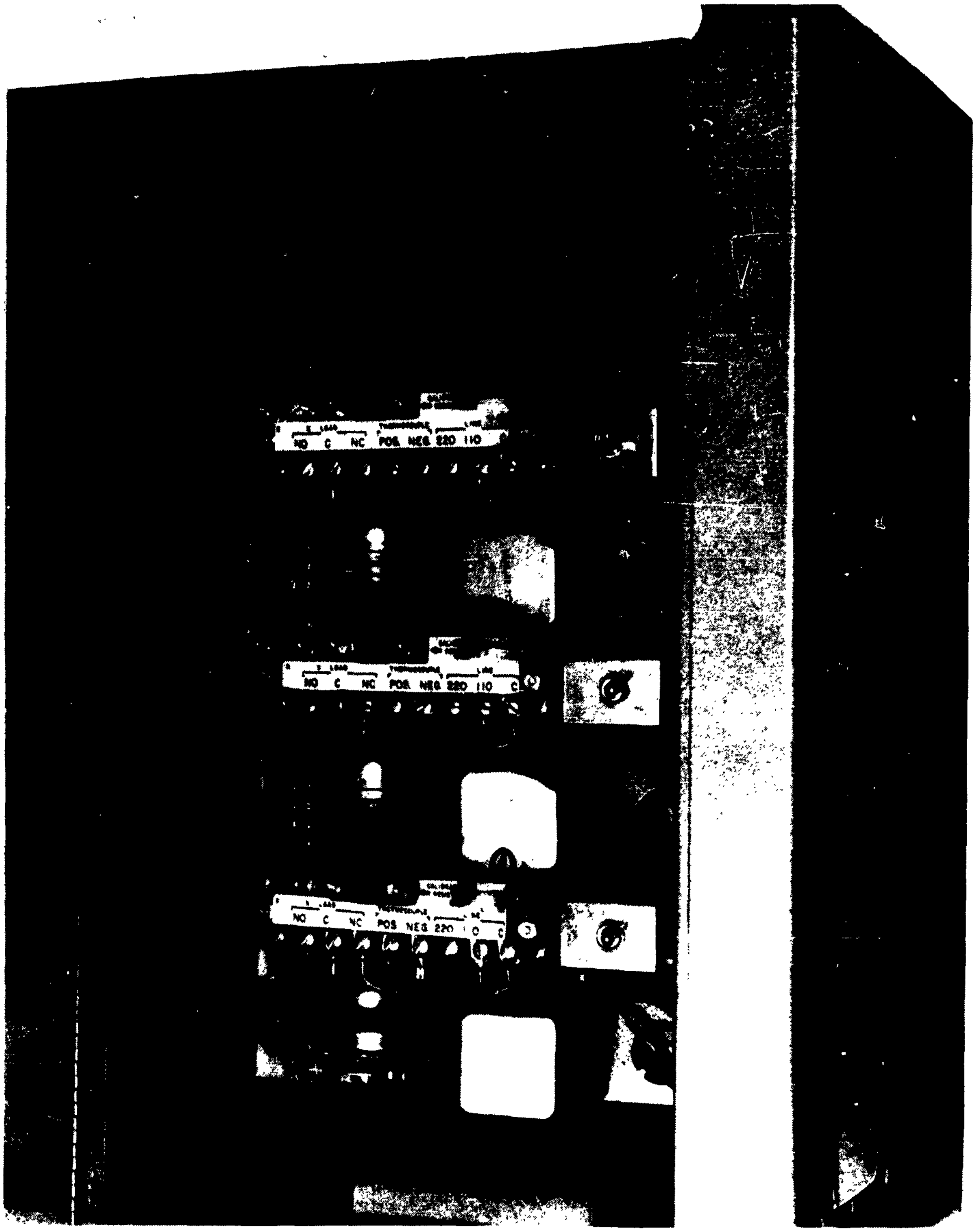

Figure 2.3-6

Prototype Control Console

(Top Inside View)

2.4 Welding Compatibility

At the conclusion of the latest vaporizer experiment, an area of extensive cesium reaction was uncovered at the vaporizer discharge. At this location the type 316 Stainless vaporizer sheath had been welded to a type 347 vapor collector tube (1/32 inch wall), the area had been exposed to a cesium vapor environment at 1000°F for approximately 30 hours. During test rig "down-time" the same section was in cesium environment at 200°F (approximately 100 hours total "down-time").

This reaction resulted in a hole, approximately 1/4 inch by 1/2 inch, penetrating the vapor discharge tube. Initial cesium vapor attack had been aggravated by high temperature oxide reaction after the initial penetration was made. After a careful disassembly of the effected parts was completed, large amounts of cesium oxides were removed and the section was forwarded to TRW's Materials Development Laboratory for evaluation.

A few representative photographs of the effected area, taken at the time of examination are included in this report. Figure 2.4-1 shows a profile of the vaporizer, vapor sheath and actual penetration. The effects of cesium oxide attack on the porous structure are very graphically denoted. Relatively unaffected areas of the matrix have retained their distinctive metallic shade. Two thermocouple wells are shown; as mentioned in Section 2.1, these were installed to reflect operating conditions within the matrix.

On the upper right hand section of 2.4-1, just above the penetration, we note a rippling effect which, it is believed, defines progressive erosion due to oxide attack. An excellent cross-sectional view of the flexible heaters used in vaporizer construction can also be noted in this photograph.

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Figure 2.4-1

Profile View of Vaporizer and Penetration Area

Figure 2.4-2 shows a cross-sectional view of the affected areas, a definite thinning out of the discharge section is to be seen just above the hole, identifying a region of progressive corrosion, possibly due to 1000°F oxides attacking braze materials in this location.

Figure 2.4-3 was included to mark the corrosive effects of cesium and cesium oxides at high temperature upon the vaporizer heater element. Destruction of one section of the heater sheath is evident as well as the wall thinning process evident in Figure 2.4-2.

In all these exhibits where the matrix has been cut for examination, surface destruction of the porous structure is evident. In past work on this project we have found that porosity in such cases can be restored by an electrostatic grinding, followed up by careful cleaning.

The results of preliminary investigation of this problem area leads us to believe that the initial penetration occurred due to preferential attack by cesium vapor on precipitated carbides deposited in the region of the type 316 weldment. Reaction was engendered by the presence of dissimilar metals (type 316 and 347 Stainless and type BT vacuum braze material). Since carbide precipitation is to be expected in all type 316 weld areas it would follow that where containment of cesium vapors at elevated temperature is involved, exposed welds of type 316 Stainless Steel should be avoided.

As a result of niobium-tantalum stabilization, a type 347 stainless weldment will not contain excessive carbide precipitates; this fact presents a solution to the welding problem. The exclusive use of 347 steel and 347 welds where a highly corrosive cesium environment is established will eliminate future serious intergranular reaction.

Figure 2.4-2

Cross Section View of Affected Area

Figure 2.4-3

Corrosive Effects on Heater Elements

This weld compatibility problem occurred during the last scheduled tests prior to prototype assembly. Due to the imminence of final system tests, metallurgical examination was expedited and a decision on prototype fabrication was made, based on the preliminary results noted above. The first prototype tests will be made using an all-type 347 stainless vapor system. The components which are not in contact with high temperature cesium vapor will be fabricated from type 316 steel as originally planned. The use of type 347 steel will not present general corrosion problems in the vapor environment since both types, 316 and 347, are considered generally acceptable from a compatibility standpoint.

The information gained from metallurgical examination of the effected regions is naturally obscured by massive erosion which followed the initial weld reaction, therefore, the assumptions made on the basis of this examination alone may not be conclusive. Further data on this problem area will be forthcoming when final reports on cesium corrosion studies just completed are available.

These corrosion tests were designed to study the effects of 1000°F, and 200°F cesium environments on types 316, 321 and 347 Stainless Steels, weldments of 300 series stainless and dissimilar material joints. Tests were run over 500 hour intervals at temperatures reflecting vapor and liquid conditions in an actual engine. At this writing the specimens are under metallographic examination.

3.0 ANTICIPATED ACTIVITIES

At the present time all prototype components have been selected and preliminary reliability tests performed. Actual component units to be integrated into the test system are fabricated and system assembly is underway.

The first phase of integrated system testing will include a check out of electrical controls and heremetic conditions. One week's equivalent endurance test with cesium represents the final development requirement of the present contract effort. Further operations will be predicated on the requirements of the program extension.

The Ion Propellant System is approximately 95% complete with an estimated completion date of April 5, 1961.